Design and Evaluation Criteria for Energy Conservation in New Buildings

In the early 1970s, one-third of the energy consumed in the United States was used to heat and cool buildings and to provide illumination, water heating, and other building services. Shortages of fuel oil, gas and electricity were quite prevalent on a localized basis in the winter of 1972-73. Temporary closing of schools, shutdowns of industry and government facilities during spells of severe weather, and electrical brownouts created strong demands in several states for regulations that would provide for equitable distribution of available supplies during periods of shortage. Responding to these demands in the spring of 1973, the National Conference of States on Building Codes and Standards (NCSBCS) requested the National Bureau of Standards (NBS) to develop a set of design and evaluation guidelines for energy conservation in buildings that states could use pending development of a national consensus standard. These requirements were to be nationally applicable and effective for buildings of all types. NBS drew on its long-term research expertise in the prediction and measurement of building thermal performance and lighting to formulate a technically and economically effective approach to the design of new energy-conserving buildings. In February 1974, shortly after the OPEC oil embargo, NBSIR 74-452, *Design and Evaluation Criteria for Energy Conservation in New Buildings* [1], became available for use.

Most states have delegated their constitutional authority for establishing and enforcing building codes to local units of government. In the late 1960s, Charles T. (Chuck) Mahaffey of NBS conceived a plan to address the problem of non-uniformity in U.S. building codes and standards, based on the way the states and NBS cooperated in the National Conference of Weights and Measures, Cement and Concrete Reference Laboratories (CCRL), and American Association of State Highway and Transportation Officials (AASHTO). As an outgrowth of an exploratory meeting in which state officials in Wisconsin played a major role, NCSBCS was formed on November 20, 1967, at an organizational meeting attended by delegates from 16 states. It was agreed that NCSBCS would provide a forum for discussing administrative problems in building regulation at the state level, and develop and seek adoption of uniform and comprehensive state building codes and standards. NBS officially furnished secretariat services from April 1970 until October 1976, housed NCSBCS until September 1976, and continued to provide technical support [2,3,4].

NCSBCS soon took up the question of regulations to conserve energy use in buildings. Its Standards and Evaluation (S&E) Committee noted that "the sense of urgency connected with the energy crises may cause some states to enact hastily prepared legislative requirements ill-suited to solving the national problems involved." At the Committee's request, Paul R. (Reece) Achenbach summarized NBS research in the field of energy use in buildings. As a result, the Committee members voted as follows:

1. [We] endorse the concept that energy conservation is of national concern and that related building design and construction is properly a building code subject.
2. Consistent with state NCSBCS objectives, uniform national performance-oriented reference standards should be generated.
3. [We] request continued NBS activity in this area, and specifically the following: Report to the S&E Committee with recommendations on the possible content and strategy for generation of a building related energy conservation reference standard, including the consideration of cost implications. Since the scope of building codes had historically been limited to life safety issues, Item 1 led to a major shift in building regulatory policy in the United States (and Canada).

In August 1973, NCSBCS formally asked for NBS assistance in developing a four-part energy conservation program, including development of a draft performance standard for state regulatory reference and call for a sponsor to act as the secretariat for eventually processing the standard through the American National Standards Institute (ANSI). NBS agreed: 1) to develop the design and evaluation criteria for energy conservation in new buildings (NCSBCS would offer these to a suitable sponsor as a basis for developing an energy conservation performance standard); and 2) to advise NCSBCS on options for advancing its criteria through the consensus process.

The 1974 energy document was developed by a 15-man NBS Task Group and 5 advisors with Reece Achenbach as Program Manager and Jim Heldenbrand as Project Manager. The Task Group investigated a number of different approaches, rating as most likely to attain the objectives a "framework of performance standards supported by performance requirements of subelements." It was chosen largely because available technical knowledge and economic tools limited a broader performance approach, and because time was short.

The resulting document [1] was regarded as primarily a component performance approach, but it also contained some specification (prescriptive) requirements and had some features of a building performance standard. As illustrated in Fig. 1, it provided three design paths for obtaining a building with acceptable design energy requirements. The basic approach was to describe the performance criteria for the components of a building envelope, and the heating, air conditioning, ventilating, domestic water heating, and lighting systems to provide for efficient use of energy. Having first determined the annual energy requirement of a given design in accordance with this basic approach, the designer could use any other combination of building and equipment characteristics that would require equal or less energy on an annual basis for the same building function. Under the third alternative, the designer would receive a bonus of up to half of any energy supplied by solar or wind-powered equipment in determining the annual energy requirements for the proposed building.

The 1974 document saw a need for more energy and economic information to improve the energy performance criteria. The information fell into four areas:

1. procedures and data for determining economic efficiency;
2. energy analysis data
   - part-load efficiency data; control characteristics
   - air distribution
   - standard weather data for energy analysis
   - engineering data for nonconventional systems
   - simplified and reliable energy calculation procedures;
3. testing procedures;
4. infiltration.

NBS was positioned to advance the state of research-based data and procedures in several of these areas. The building energy conservation program at NBS accelerated in the early 1970s, having begun with heat transfer work by the Heat Division in the first 10 years of NBS' existence and continued with the establishment of the Building Technology Division in 1947 with Douglas Parsons as its Chief. In the 1960s this work was conducted in the newly established Building Research Division with James R. Wright as Chief. Much of the building research work is documented in two series of publications, *Building Materials and Science* (over 150 publications) and the current *Building Science Series*. Building research through 1968 was well documented by Achenbach [5].

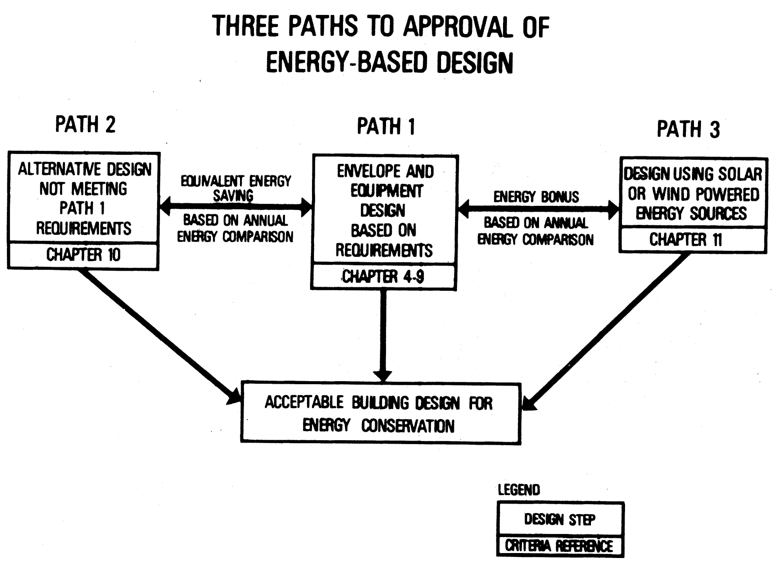

Fig. 1. Three paths to approval of energy-based design.

The energy crisis demanded more sophisticated engineering calculation methods and design, based on quantitative predictions. NBS was ready for the challenge with its background in heat transfer, use of a temperature controlled building shell enclosing a full scale bungalow at the Connecticut Avenue site for measuring efficiency of heating and cooling systems, and the experience of testing and rating heat pumps, including projects *in situ*. At the Gaithersburg site, NBS had state-of-the-art laboratory facilities, including environmental chambers for controlled temperatures from –45 °C to 65 °C (–50 °F to 150 °F) with humidity control, as well as outdoor testing facilities, including the Bowman house. Engineering (slide rule) calculations normally consisted of estimating the "steady-state" maximum heating and cooling loads using peak weather data, heat and air transfer calculations, and estimates of imponderables like occupant living patterns, rate of window and door openings, and hot water and appliance usage. When energy was cheap and readily available, this system worked well because equipment could be oversized with factors of safety. What was needed for the high-cost energy crisis was accurate predictions based on measured data, hourly weather data covering all seasons of the year in any location and the dynamic profile of hourly energy required by a proposed building design for a full year. A rapid computer capability was available for computations at NBS; the National Oceanic and Atmospheric Administration could supply hourly weather data for a whole year or for many years for many cities in the United States and globally; and the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) was rapidly coming up on the learning curve of dynamic computer calculations.

Tamami (Tom) Kusuda at NBS developed a dynamic computer calculation program called the National Bureau of Standards Load Determination Program (NBSLD), described elsewhere in this volume, to address these problems in depth. With availability of a 70,000 cubic foot environmental chamber at NBS, a series of experiments was devised to validate NBSLD using three-dimensional structures whose exteriors could be subjected to dynamic temperature and humidity boundary conditions. The results of experimental validation testing of NBSLD were published in Building Science Series (BSS) 45 in 1973 [6] and in BSS 57 in 1975 [7]. The response factor space load prediction methodology of NBSLD was found to be accurate, and the agreement between calculated and observed heating energy rate was considered excellent. This work had landmark impact because the tools for energy design and savings procedures were convincingly demonstrated to be reliable.

NBS recommended that its 1974 energy conservation document be used as a basis for development of a national voluntary consensus standard. NCSBCS requested that ASHRAE process the NBS report as a national consensus standard [1]: ASHRAE established an extraordinary effort to analyze and refine the NBS report and, in August 1975, published ASHRAE Standard 90-75 (revised 1977) Energy Conservation in New Building Design, with the technical support of IES (now IESNA).

In January 1977, representatives of NCSBCS and the three model building code organizations put ASHRAE 90-75 into code language under sponsorship of the Energy Research and Development Administration (ERDA) and submitted it to public review and hearings. In December, 1977 the final version was published by the Council of American Building Officials (CABO). Subsequent revisions are known as the Model Energy Code (MEC) [8]. Over the ensuing decade, all 50 states enacted regulations based on the ASHRAE 90 Series Standards, the Model Energy Code, or one of several regional and State codes that also used these ASHRAE Standards as a technical base. ANSI approved a jointly sponsored revision, ANSI/ASHRAE/IES 90A-1980, as an American National Standard [9]. Standard 90A-1980 was a revision of Sections 1-9 of ASHRAE 90-75. An addendum was issued in 1987 to supplement the residential requirements in 90A.

In view of the need for more procedures and data for determining economic efficiency, the NBS/CBT Office of Applied Economics (OAE) addressed the U.S. Department of Energy's (DOE) Building Energy Performance Standards (BEPS) program—and the need to revise ASHRAE Standard 90 to save more nonrenewable energy—with three publications published in 1978-81: *The Role of Economic Analysis in the Development of Energy Standards for New Buildings* [10], *A "Reference Building" Approach to Building Energy Performance Standards for Single-Family Residences* [11], and *Economics and Energy Conservation in the Design of New Single-Family Housing* [12]. These economic applications to standards for building energy design were based on principles published in 1974 by Stephen R. Petersen in BSS 64 [13] and on OAE Chief Harold E. Marshall's support of development by ASTM Committees of consensus standards for economic definitions, terms and practices as tools for evaluating energy conserving investments in buildings and building systems [14]. OAE wrote a separate NBSIR report as the basis for each of these ASTM

Standards. These standards have come into use world wide for making both energy and other types of building investment decisions. The economic methods and software initiated with Petersen's work in 1974 and continued to the present have provided the underpinnings of ASTM standard methods universally used for evaluating the economics of energy conservation in buildings.

In 1983-84 the ASHRAE 90 project was reorganized into two project committees, 90.1 covering commercial and high-rise residential buildings and 90.2 covering low-rise residential buildings. A major revision of the commercial building requirements, ASHRAE/IESNA 90.1-1989, was approved by the ASHRAE Board of Directors (BOD) on June 24, 1989 for publication, later updated by seven addenda. ANSI approved ANSI/ASHRAE/IESNA 90.1-1989 with addenda as an American National Standard on July 9, 1996 [15]. In this revision, the complexity and size of the Standard 90 Series was considerably increased by incorporating building design criteria based on dynamic (e.g., diurnal) heat flow analysis and hourly weather conditions rather than assuming steady-state conditions.

ASHRAE/IES Standard 90.1-1989 for commercial and high-rise residential buildings and the CABO Model Energy Code 1992 for low-rise residential buildings were referenced as minimum requirements in Congressional legislation entitled the Energy Policy Act of 1992 [16]. An energy conservation standard for federal buildings was also developed by DOE under this Public Law and published in DOE regulations, in recognition of different tax laws and economic objectives.

During the 1990s, Standing Standard Project Committee (SSPC) 90.1 maintained the standard by issuing numerous addenda and three public reviews of a major rewrite. The ASHRAE Board of Directors (BOD) voted on June 24, 1999 to approve publication of the revised Standard 90.1-1999 as an ASHRAE/IESNA Standard [17] (Fig. 2), pending ANSI approval of the

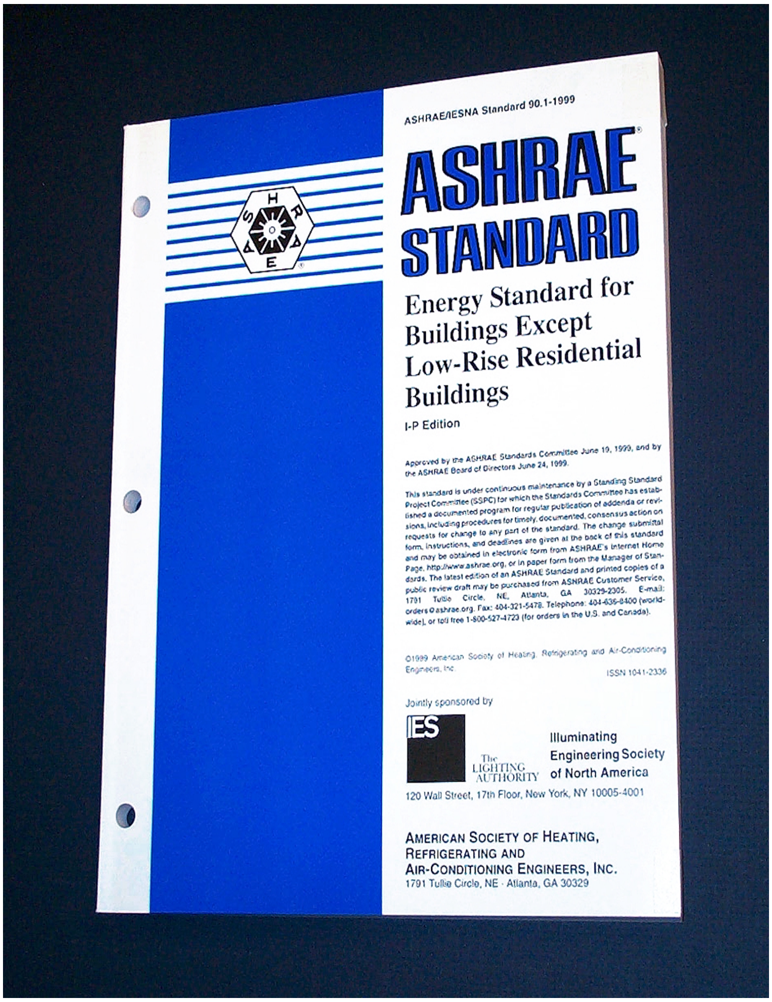

Fig. 2. ASHRAE/IESNA Standard 90.1-1999, *Energy Standard for Buildings Except Low-Rise Residential Buildings.*

revision as an American National Standard. This revision incorporates nine addenda to 90.1-1989, a reorganized document, scope expanded to cover new systems and equipment in existing buildings, code compatible language, and publication in separate IP (inch-pound) and SI versions. More than two-dozen newly proposed addenda were also recommended by the SSPC for public review approval. Over the years, the Standard 90 Series has been the best seller among ASHRAE Standards.

A case study in NISTIR 5840, *Benefits and Costs of Research: Two Case Studies in Building Technology* [18], provided estimates of the economic impacts from past BFRL research leading to the introduction of ASHRAE Standard 90-75—specifically, that portion of the standard dealing with single-family residential energy conservation. The goal of this study was to demonstrate how standardized evaluation methods can be used to evaluate the benefits and costs of research. The energy costs of houses designed according to 90-75 was compared to those of pre-1973 oil embargo standards. More than $900 million (in 1975 dollars) of the energy savings from 90-75 modifications in single-family houses were directly attributable to BFRL activities that promoted the development of ASHRAE 90-75.

The late Paul R. Achenbach, a mechanical engineer and chief of the Building Environmental Division of the Center for Building Technology, was born in Alberta, Canada. During his 43 year career at NBS, which started in 1937, he pioneered many new developments in the testing, evaluation, and modeling of the performance of building heating and air-conditioning equipment. Many dealt with improving the energy efficiency of this equipment and buildings decades before a concern for energy conservation became widespread. He initiated the programs on energy conservation in buildings and communities at NBS in 1970, for which he received the Department of Commerce Gold Medal in 1975. He had previously received the DOC Silver Medal in 1956 and the NBS Edward B. Rosa Award in 1970 for outstanding achievement in the development of engineering standards.

Throughout his career, Achenbach placed great emphasis on getting his work and that of his staff transferred into practice through the publications, conferences, and standards of ASHRAE. He served on the ASHRAE Board of Directors, and as its Vice President, receiving its Distinguished Service Award; he was named a Fellow and received its highest award for technical achievements, the F. Paul Anderson Award. He served as the Department of Commerce representative on the U.S. National Committee of the International Institute of Refrigeration (IIR) and was an honorary president of Commission VII of IIR.

Prepared by Jim L. Heldenbrand.

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